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Internet of Things-Based Worker Physical Condition Monitoring

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Abstract -- The weather conditions are uncertain, which impact performance, occupational health, and safety. To reduce the risk of fatal work accidents, the most important thing is to monitor the physical condition of workers. This research focuses on designing and implementing a real-time IoT-based system for monitoring the physical condition of workers. The system is based on three primary indicators: body temperature, heart rate, and Oxygen saturation. The MLX90164 sensor is used for measuring body temperature, while the GY-MAX30100 sensor is used for measuring heart rate and Oxygen saturation. ESP32 as a microcontroller, and then the data is displayed on the MQTT IoT Panel application on a smartphone and OLED display. The test was done to evaluate the performance of the sensor, device, and data transmission. The test results indicate that the system is running well in terms of network performance. The Quality of Service test for the MQTT Protocol indicated that QoS 0 achieved the highest throughput at 694,94 Kbps. In contrast, QoS 2 has the highest jitter and delay, measuring 4,11 ms and 4,007 ms respectively. There was no packet loss across all QoS levels. The device test also shows a low error value, which is below 4%.

Keywords:
Internet of Things
Body Temperature
Heart rate
Oxygen Saturation
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I. INTRODUCTION

Every human being has the possibility of contracting a disease that can lead to health problems. Disease outbreaks can usually be through transmission or through the influence of risk factors caused by work and the work environment, especially in workers who work in the field [1]. Not only field workers but also other workers are often faced with physically and mentally demanding conditions. Erratic weather conditions, exposure to extreme temperatures, heavy workloads, and long work durations can cause physical fatigue. This will have an impact on productivity, occupational safety, and health.

From the above problems to reduce the level of work accidents that result in loss of life, the physical condition of workers can be monitored from several indicators, including heart rate, oxygen saturation, and body temperature. To determine whether heart rate, oxygen saturation, and body temperature are normal or not, an assessment is needed both by experts and using measuring instruments [4]. Heart rate is a physiological parameter that reflects the body's response to physical activity and stress levels [11]. Excessive physical activity can cause a significant increase in heart rate, thus affecting the body's capacity to work optimally [10]. Body temperature is a description of the metabolic process of living things that can run smoothly or experience a disturbance [2]. Human body temperature can increase due to strenuous physical activity and exposure to high temperatures. Exposure to high temperatures can cause increased heart work, excessive sweating, and dehydration, which results in a thermal imbalance in the [12]. These conditions can cause worker discomfort to increase the risk of fatigue and serious health problems such as heat stroke. In addition to heart rate and body temperature, oxygen saturation also has an important role in determining the level of worker fatigue. Oxygen saturation is the percentage of hemoglobin in the blood that is bound to oxygen [8]. Oxygen saturation describes how effectively oxygen is transported throughout the body through the blood. A decrease in oxygen saturation can cause the body to lack energy to perform physical activities, which in turn can increase the risk. Heart rate and oxygen saturation in the blood are important aspects for the health of the human body. This aspect is very effective in determining the health of the human body. A normal heart rate (60- 100 per minute) can help in transporting oxygen throughout the body. If the heart rate is abnormal, it can be a sign of health problems. Normal oxygen saturation in the blood (95%-100%) can help the performance of the heart so that the human body does not easily experience fatigue [7]. Normal human body temperature ranges from 35℃ to 38℃ according to the World Health Organization. Body temperature can also be an indicator of a dehydrated body due to extreme weather. Poorly monitored fatigue can lead to decreased performance, increased risk of work accidents, and even long-term health problems.

Several researchers have previously examined body temperature using the Melexis90164 or MLX90164 sensor such as those conducted by Helmy Yudhistira and friends with the research title Designing a Body Temperature Meter with Multi Sensors to Prevent the Spread of Covid-19. In this study, the microcontroller used was WemosD1R2, an MLX90614 sensor to measure human body temperature, and a High Conductance ultrasonic sensor 04 or HC-SR04 distance sensor to measure the distance between the device and the human forehead. If the system detects a temperature > 37.5 ° C, the buzzer will turn on [6]. Furthermore, Herdiansyah and friends designed an oxygen saturation and heart rate measurement tool entitled Design of Arduino-Based Oxygen Saturation and Heart Rate Measurement Tool Using Modulated Air Quantity Sensor30100 or MAX30100 and Liquid Crystal Display or LCD. In this study compared the results of sensor measurements and pulse oximeter measurements [7]. Rakhmawati also made a body temperature measuring instrument with the title Implementation of Human Body Measurement Tools Using Arduino-Based MLX90164 Touchless Sensors. Using Arduino Uno as the system controller [9]. Venica has researched fatigue detection systems with the title IoT with Firebase: Smart Ring Android APP Using MAX30100 for Fatigue Detection. By focusing on developing the software component (Android application) and database management system of the smart ring IoT System, the Android-based smart ring application is able to monitor three conditions of the user's body to predict the user's body condition [13]. From some of these studies, it can be concluded that the two MAX30100 and MLX 90164 sensors can be used to detect body conditions with heart rate, oxygen saturation, and body temperature parameters. However, there are several things that must be developed in the research, such as not implementing on workers to monitor body conditions to avoid fatal incidents, such as work accidents.

Therefore, monitoring heart rate, oxygen saturation, and body temperature is important for monitoring the condition of the human body to prevent fatal events such as accidents in the industry. On the basis of the above problems, the author conducted research on designing a tool to detect body conditions in workers who can monitor heart rate, oxygen saturation, and body temperature of workers in real time using the Internet of Things.

II. METHODS

Figure 1 shows the research flowchart related to the methods used by the authors to obtain the required data. The chart outlines the steps taken during the research, beginning with the initial problem identification, followed by the testing procedure and data analysis.

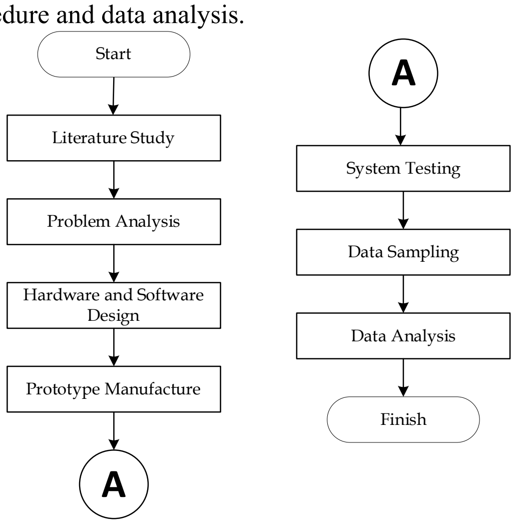


Figure 1 Research Flowchart

A. Literature Study

At this stage, the researcher conducts a study by exploring scientific papers that are relevant to the topic to be researched. This stage aims the aim that researchers understand basic concepts, current technology, and methods that have been used in similar studies. This stage begins by reviewing reliable sources such as scientific articles, journals, and relevant research reports discussing the title under study, namely physical condition detection with three indicators, namely heart rate, oxygen saturation, and body temperature.

B. Problem Analysis

At this point, the author examines the issue raised by the findings of the preliminary research and literature review. Finding discrepancies between the ideal and actual field conditions is the goal of this analysis. The author can ascertain the extent and boundaries of the problem.

C. Hardware, Software Design, and Prototype Manufacture

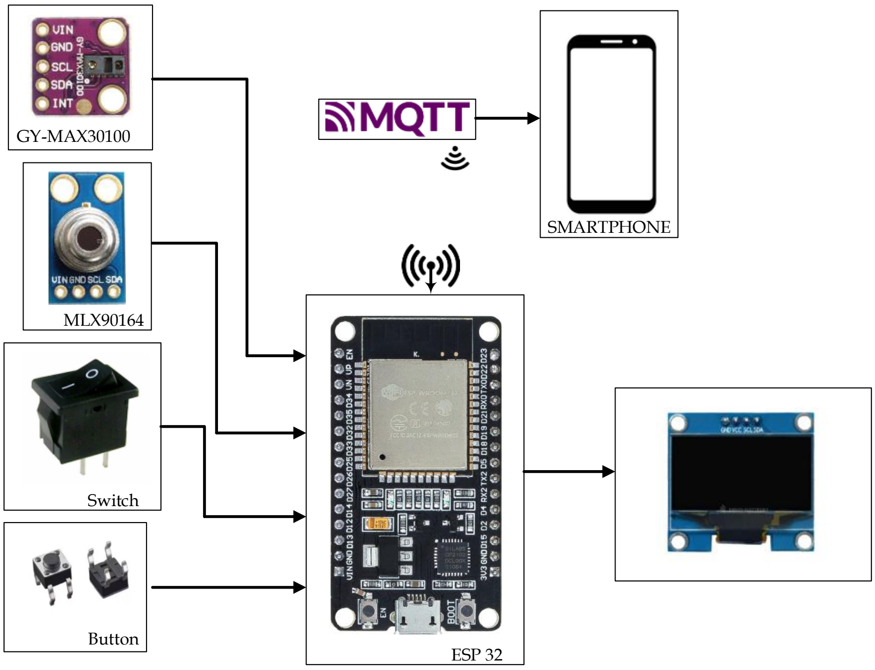


Figure 2 Hardware Design

The process begins with building a system using programs on the software Arduino IDE. using Arduino IDE (Integrated Development Environment) software. Data from both sensors is collected periodically, the software will use the if..else method to analyze the data received. The results will be forwarded to the MQTT broker using the MQTT communication protocol. The MQTT Client will receive the three indicators of the worker's physical condition. The system will display on the application. OLED will display the three indicators from the data that has passed the pre-message.

Based on this figure, it can be seen that the switch is the power button on this tool. Then there is also a pushbutton as a measurement mode changer on one of the sensors. GY-MAX30100 and MLX90164 sensors as sensors that take data from the tool. Data obtained from the two sensors will be sent to the ESP32 as a microcontroller for data processing. The data received by the sensor will detect three physical body indicators, namely heart rate, oxygen saturation, and body temperature. The data that has been processed will be sent by ESP 32 with Wi-Fi to the MQTT broker, which is then forwarded to the MQTT Client. The MQTT Client will monitor the status of the worker's physical condition with these three indicators. The output results will be displayed by OLED display (Organic Light Emitting Diode) as the output of the Internet of Things-based worker body condition detection tool. Notifications sent by the application contain information about body temperature (°C), blood oxygen levels (SpO2), and heart rate (BPM). A flowchart of the MQTT IoT-based worker Detection monitoring can be seen in Figure 3 below.

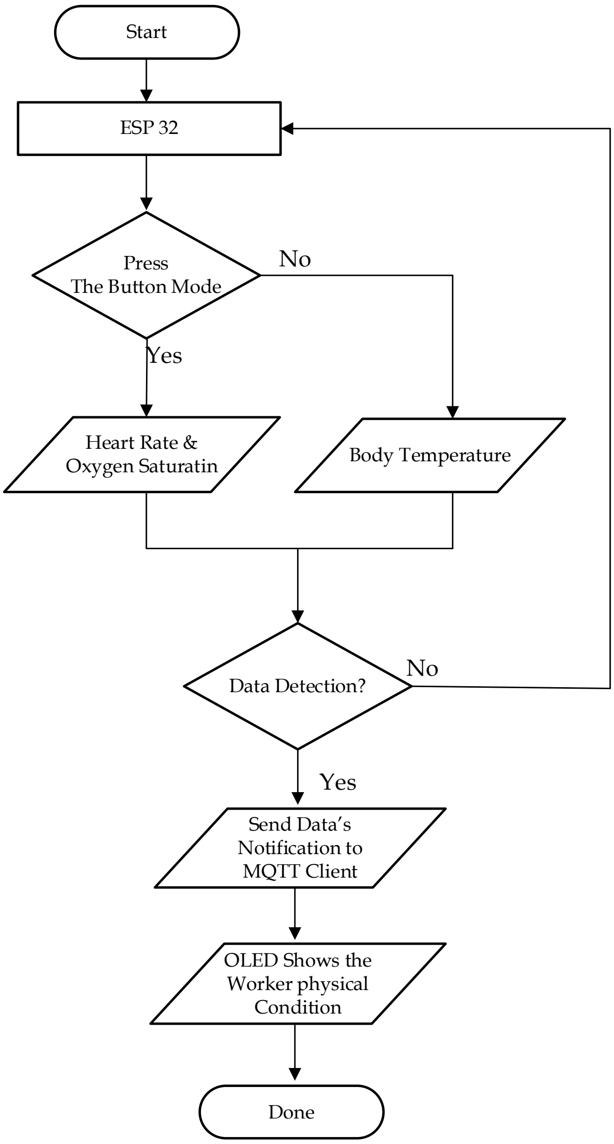


Figure 3 Flow Chart

D. System Testing

Prototype testing is the next stage, which tries to assess the device's performance and determine whether it operates as intended. There are four tests for this system. There are tools to test to ensure that all components function properly and in accordance with the design. The second MQTT test is performed to ensure the reliability and performance of data can be sent by the system to the IoT platform and vice versa, and commands from the IoT platform can be received by the system properly. The third test is the MQTT Quality of Service test to evaluate the speed and reliability of data transmission from ESP32 devices to IoT servers via the MQTT communication protocol. QoS testing involves measuring several parameters, such as Throughput, Delay, Jitter, and Packet Loss. The last test is a device test that evaluates the precision and constraints of health data readings from the MLX90164 and GY-MAX30100 sensors by comparing sensor measurements to standard medical measurements. Using parameters such as error value and percentage error, the readings are tested to ensure the sensors work optimally and produce accurate data. Error Percentage can be calculated according to [3] with the equation:

$$\%Error = \frac{|x - x1|}{x} \times 100\% \text{ .... [1]}$$

Throughput is the amount of data successfully transmitted over a network in a given period. In short, throughput is a reflection of the effective speed of the network. Throughput can be calculated according to [5] with the equation:

$$\text{Throughput} = \frac{\text{Number of Data Sent}}{\text{Total Delivery Time}} \ldots [2]$$

Delay is the time it takes for data packets to travel from the transmitter to and receiver. Delay can be calculated according to [5] with the equation:

$$\text{Delay} = \text{packet time received - packet time sent} \ldots [3]$$

Jitter measures the consistency of the data delivery time. It can be calculated using the following equation [5]:

$$\text{Jitter} = \frac{1}{N-1} \sum_{i=1}^{N-1} |Delay(i+1) - Delay(i)| \ldots [4]$$

Packet loss indicates packet loss in the delivery process, which can be caused by bottlenecks in the network or overloading that causes packet buildup and eventual packet loss. It can be calculated using the following equation [5]:

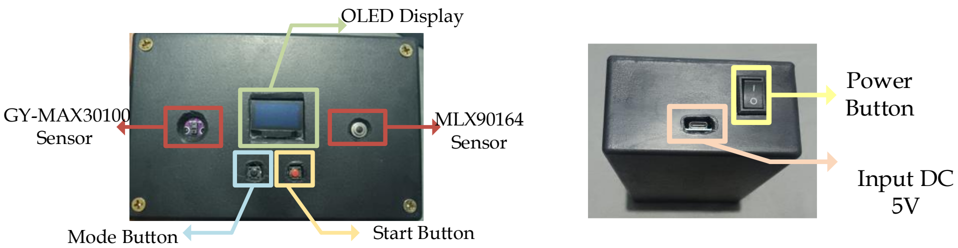
$$\text{Packet-loss} = \left(\frac{\text{Data Sent} - \text{Data Packets Received}}{\text{Data Packets Received}}\right) \ldots [5]$$

E. Data Analysis

The data obtained from both sensors will be sent via the MQTT (Message Queuing Telemetry Transport) communication protocol to ensure efficient and real-time data transmission with the Internet of Things. In addition, this stage also includes designing the system architecture and analysis methods used to detect fatigue patterns based on the measured parameters. With this approach, it is expected that the system can provide accurate and reliable monitoring of worker conditions to prevent the risk of fatigue-related accidents.

III. RESULT AND DISCUSSION

The research has produced a device that functions according to the specifications built. The system-built shows that the system on the device can receive input from three parameters, namely heart rate, oxygen saturation (SpO2), and body temperature in real time, and monitored through the MQTT IoT Panel (Message Queuing Telemetry Transport Internet of Things) application which uses the MQTT IoT protocol as an administrator. The hardware is illustrated in the figure below.



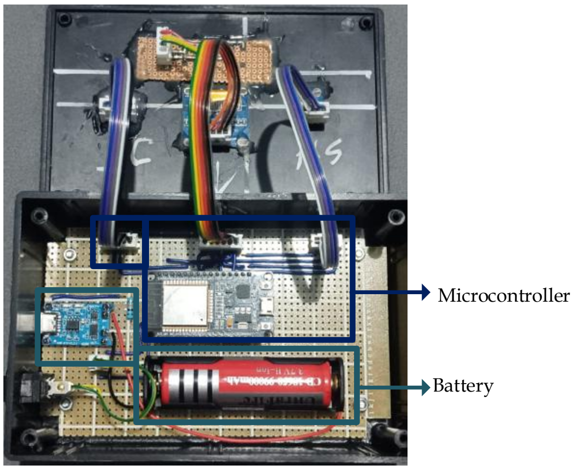


Figure 4 Hardware Result

A. Tool Test

1. Battery

The battery plays a role as the main supply in this physical condition monitoring system for workers. As a source of voltage for all devices, this system uses 18650 batteries with 3.7 Volts as a portable voltage source that can be used in the user's field because practical. The table below shows the results of battery voltage measurement.

TABLE I VOLTAGE SOURCE MEASUREMENT

Voltage	Uses	Measurement
3,7 V DC	Battery	3,98 V DC
	ESP32	3,93V DC
3.3 V DC	GY-MAX30100	2,78V DC
	MLX90164	2,82V DC
	OLED	2,80V DC

Overall, the 18650-battery power supply system can provide a stable voltage and close to the optimal value for all components in the body condition monitoring system for workers. The voltage distribution on the ESP32, GY-MAX30100 sensor, MLX90164 sensor, and OLED display shows good consistency.

2. Microcontroller

The microcontroller in this project uses ESP32 (Espressif System 32), which operates at a voltage of 3.3 volts. ESP32 functions as the brain of the system built which is attached to the PCB (Printed Circuit Board) and pin sockets as a connector with the GY-MAX30100 sensor (GY-Modulated Air Quantity Sensor30100), MLX90164 sensor (Melxis 90164), and OLED (Organic Light Emitting Diode), switch, and measurement mode button. After the program is uploaded, an initial sensor initialization reading is performed to ensure that the connected sensor can be recognized and initialized correctly by the ESP32 as a microcontroller. In Figure 5 can be seen above on the Arduino IDE serial monitor shows the success of the microcontroller loading all aspects of the device, including Wi-Fi, MQTT, MAX30100, and MLX90164 sensor readings after the program has been successfully uploaded.

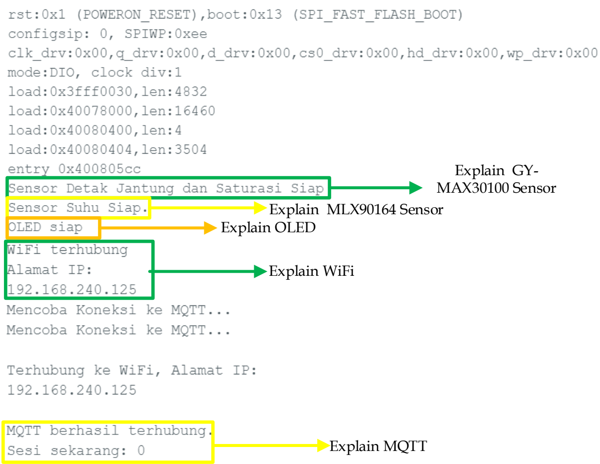


Figure 5 Serial Monitor Display of ESP 32 Initial Initialization

3. *Sensor*

The sensors used in this project use the GY-MAX30100 sensor (GY-Modulated Air Quantity Sensor30100) for measuring heart rate and oxygen saturation (SpO2) and using the MLX90164 sensor (Melxis90164) for measuring body temperature. Figure 6 shows the value measurement result of both sensors.

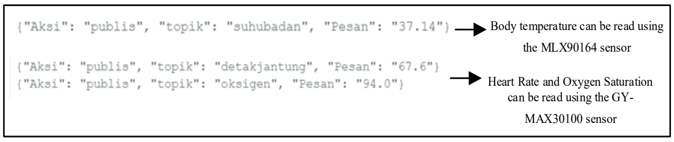


Figure 6 Value Measurement Result of Both Sensors

4. *OLED Display*

The OLED (Organic Light Emitting Diode) display on the system is used to display some system status on the physical condition monitoring in real time. There are three status modes in the OLED display. The first status is a measurement status that indicates the measurement mode that is currently active in the system, The user can switch the measurement mode using the black button. The second status is sensor counting status, which is an ongoing measurement process for one minute by GY-MAX30100 (GY-Modulated Air Quantity Sensor30100) and MLX90164 (Melxis90164). The last one is the final result status is a final calculation value in the form of the average value of all data that has been obtained during the previous one-minute measurement. The picture below shows the display OLED structure.

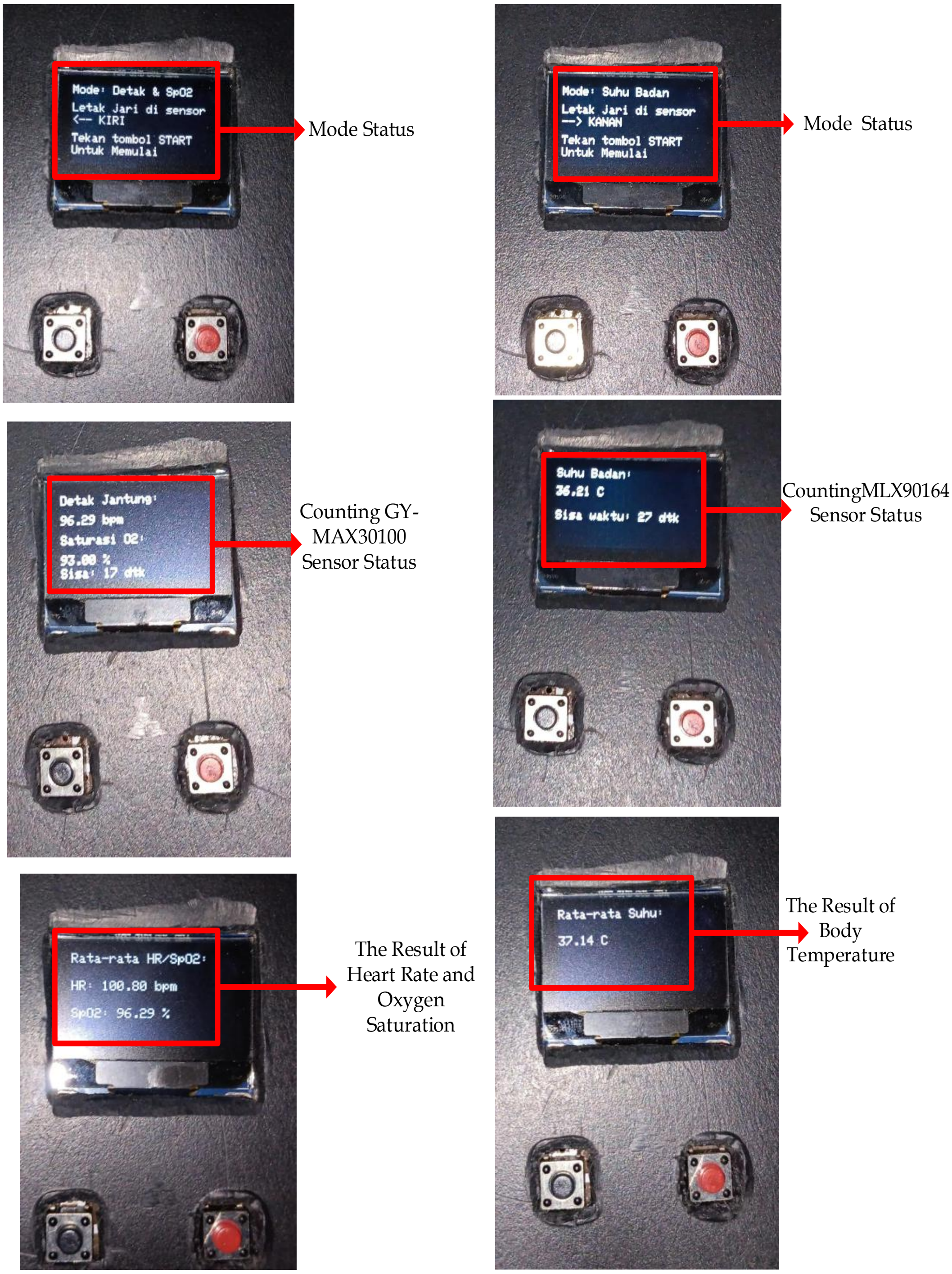


Figure 7 OLED Display Structure for Heart Rate, Oxygen Saturation, and Body Temperature

5. *MQTT Test*

MQTT IoT (Message Queuing Telemetry Transport Internet of Things) testing is carried out on the ESP32 microcontroller connected to a local broker, in this system using the Mosquitto broker. The hardware used includes a personal computer or laptop that functions as a host for the Mosquitto broker. the log of the Mosquitto broker implementation results, which records various activities during testing, data transmission, and MQTT topics used in the system, can be seen in Figure 8.

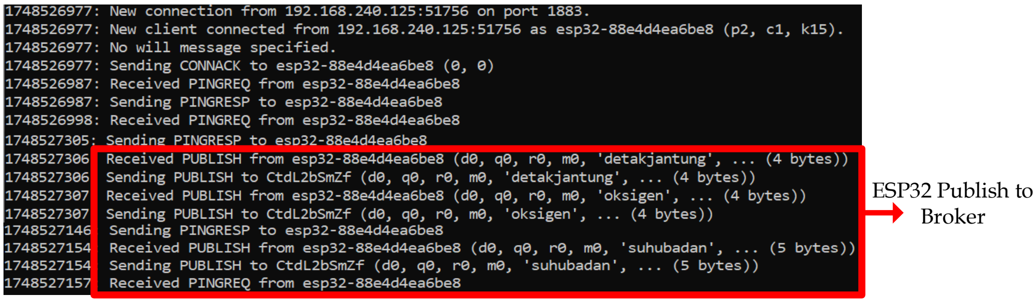


Figure 8 Mosquitto Local Broker Activity Log

B. Message Queuing Telemetry Transport

MQTT (Message Queuing Telemetry Transport) network testing is done by analyzing Throughput, Delay, Jitter, and Packet Loss as a tool response to the MQTT IoT protocol using Wireshark software. Testing is done using three QOS (Quality of Service), namely QOS 0, QOS 1, and QOS 2.

1. Throughput

In throughput testing, using Wireshark software, which calculates based on the number of bits that have been recorded over a time range. The result of the division produces throughput in units of Bps (bits per second). For interpretation in this test, using Kbps (Kilo Bits per second) data.

TABLE II THROUGHPUT TESTING RESULT

No.	Second	Throughput (KBps)		
		QoS 0	QoS 1	QoS 2
1.	1	779,06	588,9	540,45
2.	2	804,37	348,68	526,63
3.	3	534,46	341,48	557,75
4.	4	683,37	348,45	545,36
5.	5	766,17	303,84	550,41
6.	6	599,68	573,8	577,48
7.	7	697,64	313,99	562,08
Average		**694,96**	**402,73**	**551,45**

Based on Table 2, it can be seen that QoS 0 produces a throughput of 694.96 Kbps (kilobits per second), which means that this level of QoS has high performance in data rate. This can happen due to the lack of overhead since the transmission is done without confirmation or repetition mechanisms. Meanwhile, QoS level 1 has an average value of 402.73. This decrease occurs due to the acknowledgment mechanism, which is a confirmation mechanism that slows down the delivery process, even though it guarantees that the message is sent once. This process results in additional communication load, which causes the throughput value to decrease. Throughput with QoS level 2 is 551.45 Kbps. This value is a result of a complex two-phase confirmation mechanism that aims to ensure each message is received exactly once without duplication. This allows the receiving system to process messages more efficiently, so that under certain conditions, QoS 2 produces higher throughput.

2. Delay

The delay test is carried out with the aim of knowing the delay time required in the data transmission process on the system. Delay is tested with QoS 0, QoS 1, and QoS 2 to find out the difference between QoS.

TABLE III RESULT OF TESTING DELAY

No.	Second	Delay(mS)		
		QoS 0	QoS 1	QoS 2
1.	1	2,98	2,39	3,73
2.	2	1,23	2,8	5,71

3.	3	1,03	2,74	3,87
4.	4	0,92	2,57	3,48
5.	5	1,07	2,71	4,02
6.	6	1,04	2,44	3,63
7.	7	1,10	3,1	3,61
Average		**1,33**	**2,67**	**4,007**

Based on the delay test results in Table 3 above, the highest delay value in QoS 2 is 4.007 milliseconds, followed by QoS 1, worth 2.67 milliseconds, and QoS 0, which has the lowest value of 1.33 milliseconds. This is because QoS 0 does not involve confirmation and receiving mechanisms. While QoS 1 is slightly higher than QoS 1 due to the confirmation process to ensure that the message is received at least once. QoS 2 has the highest value due to its more complex process, which involves four stages to guarantee delivery exactly once.

3. Jitter

Jitter testing aims to measure the variation of delay time between data packets received during the transmission process. Through this jitter test, it can be evaluated how much influence the QoS level has on the stability of data transmission time, and can choose the most appropriate QoS level.

TABLE IV JITTER TESTING RESULT

No.	Second	Jitter (mS)		
		QoS 0	**QoS 1**	**QoS 2**
1.	1	3,59	1,59	3,67
2.	2	0,58	1,59	6,59
3.	3	0,49	1,55	3,84
4.	4	0,34	1,66	3,48
5.	5	0,41	1,03	4,04
6.	6	0,35	1,4	3,63
7.	7	0,40	2,3	3,56
Average		**0,88**	**1,55**	**4,11**

The test results can be seen in Table 4.6 above. The highest and lowest jitter values, respectively, are at QoS 2, worth 4.11 milliseconds, then QoS 1, worth 1.55 milliseconds, and the last QoS 0 has an average value of 0.88 milliseconds. The value in QoS 0 shows the stability of the time between packet delivery because there is no confirmation process or repetition of delivery. QoS 1 has a slightly higher average than QoS 0 due to the confirmation mechanism that can cause variations in time between transmissions. Similarly, QoS 2 has the highest value due to the four stages of the delivery process, which have the potential to cause irregular time between packets. Even so, the system can operate properly.

4. Packet Loss

Packet loss testing is carried out to measure data packets lost during the delivery process. The existence of packet loss is caused by several factors, such as signal degradation in network media, exceeded network capacity, corrupt packets that refuse to transit, and network hardware errors.

TABLE V PACKET LOSS TESTING RESULT

No.	Second	Packet loss (%)		
		QoS 0	**QoS 1**	**QoS 2**
1.	1	0	0	0
2.	2	0	0	0
3.	3	0	0	0

4.	4	0	0	0
5.	5	0	0	0
6.	6	0	0	0
7.	7	0	0	0
	Average	**0**	**0**	**0**

It can be seen in Table 5 that the results of the packet loss test above have no packets lost at all QoS levels, whether QoS 0, QoS 1, or QoS 2. The results show an average packet loss of 0%, which means that data transmission runs stably without any errors in packet loss, even though it uses different delivery mechanisms for each QoS.

The result of 0% packet loss in QoS 0 shows that even though it does not have guaranteed message delivery, network conditions support data transmission without packet loss. QoS 1 has the same result, meaning that the acknowledgment mechanism works well in ensuring that the acknowledgment mechanism works well in ensuring the message can be sent at least once. QoS 2 with the same results proves that the four-way handshake protocol works effectively to guarantee delivery without duplication or data loss.

C. Device Test

Comparison of body temperature readings between the MLX90164 sensor device (Melxis90164) and a digital thermometer is needed to test the quality and accuracy of temperature readings in this project. In addition, a comparison of heart rate and oxygen saturation readings between the GY-MAX30100 sensor (GY-Modulated Air Quantity Sensor30100) and a pulse oximeter is also needed to test the quality and accuracy. The test was conducted using seven samples of body temperature, heart rate, and oxygen saturation readings. This means seven measurements on each sensor, and seven measurements on the thermometer and oximeter. This test is carried out with a percentage error to see the quality of the sensor. The calculation of the percentage error can use the equation [1]. The results of the percentage error can be seen in tables 6 to 8 below, which describe the body temperature testing by the MLX90164 sensor, Oxygen Saturation, and Heart rate measured by the GY-MAX30100 sensor.

TABLE VI ERROR VALUE OF BODY TEMPERATURE

No	Respondent	System Testing	Device Testing	Error system (%)
1.	Muris	36,91	36,8	0,29%
2.	Rahmad	36,56	36,5	0,16%
3.	Daud	35,6	35,7	0,28%
4.	Farid	35,75	35,9	0,41%
5.	Nur	33,52	33,9	1,13%
6.	Zainul	36,32	35,3	2,8%
7.	Sunyoto	36,55	36,4	0,41%
			Average	**0,78%**

TABLE VII ERROR VALUE OF HEART RATE

No	Respondent	System Testing	Device Testing	Error system (%)
1.	Muris	74,5	78	4,69%
2.	Rahmad	73,35	77	4,97%
3.	Daud	95,03	95	0,031%
4.	Farid	113,37	119	4,96%
5.	Nur	86,94	84	3,38%
6.	Zainul	92,74	97	4,59%

7.	Sunyoto	64,26	65	1,15%
			Average	**3,39%**

TABLE VIII ERROR VALUE OF OXYGEN SATURATION

No	Respondent	System Testing	Device Testing	Error system (%)
1.	Muris	95,90%	98%	2,18%
2.	Rahmad	95,59%	98%	2,52%
3.	Daud	93,97%	99%	5,35%
4.	Farid	95,31%	99%	3,87%
5.	Nur	94,38%	98%	3,83%
6.	Zainul	95%	99%	4,21%
7.	Sunyoto	95,65%	99%	3,50%
			Average	**3,64%**

Body temperature testing shows a low error value of 0.78%, heart rate testing has an error value of 3.41%, and Oxygen saturation testing has the highest error value of 3.64%. The data on the variation of error values between these parameters shows that the MLX90164 sensor has good precision. While the GY-MAX30100 sensor requires further calibration. The test results in tables 6 to 8 show that although there are differences in readings between standard medical measuring instruments and the system, the error values obtained are relatively small for each parameter. This shows that the device has good accuracy and is sufficient to be relied upon in monitoring the physical condition of workers.

IV. CONCLUSION

Based on the research that has been done on monitoring the physical condition of workers working at CV MS Production which is engaged in powder coating finishing services with three parameters namely heart rate, body temperature, and oxygen saturation using the MQTT IoT protocol (Message Queuing Telemetry Transport Internet of Things) can be concluded as follows.

1. The worker's body condition monitoring device has been successfully implemented using ESP 32 as the microcontroller, MLX90164 sensor as the temperature sensor, GY-MAX30100 sensor as the heart rate and oxygen saturation detection sensor, and MQTT IoT to monitor in real time.
2. The QoS (Quality of Service) test results of the MQTT IoT protocol show adequate network performance with average QoS 0, 1, and 2 throughput values of 694.96 Kbps, 402.73 Kbps, and 551.45 Kbps, respectively. QoS for Delay parameters with an average value of 1.33ms for QoS 0, 2.67ms for QoS 1, and 4.007ms for QoS 2. QoS on the Jitter parameter for QoS levels 0, 1, and 2 has an average of 0.88mS, 1.55mS, and 4.11mS, respectively. As well as QoS for packet loss parameters is good and stable because no packets were found lost at all QoS levels tested.
3. Testing of workers' physical condition monitoring devices by comparing sensor measurements and medical standard measuring instruments to determine the error value also has a fairly satisfactory average value of 0.78% for body temperature testing. 3.41% for heart rate testing and 3.64% for Oxygen saturation measurements. This figure is relatively small because the value that appears is <4%, which can affect the diagnosis.

Overall, this IoT-based worker physical condition monitoring device is quite effective in measuring three parameters, namely body temperature, heart rate, and oxygen saturation, with stable network performance and real-time monitoring capabilities. This system offers an innovative and practical solution as well as user convenience for monitoring the physical condition of workers in an enterprise.

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